VESAT: THE VENUS ENVIRONMENTAL SATELLITE ,1'1'1; 1} ISC0W;R% MISSION

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ABSTRACT

The Venus Environmental Satellite (VESAT) is being developed by the Jet Propulsion Laboratory, Ball Aerospace, the University of Wisconsin, and Oxford University as an inexpensive but effective means of assessing numerous and interrelated dynamical and chemical processes within the deep atmosphere of Venus. Utilizing a small array of remote-sensing instruments designed to take advantage of several unique characteristics of this alien environment, VESAT daily acquires quantitative thrc.c-dimensional global maps of Venus in kcy environmental field parameters such as windfields, atmosphere/ surface temperature fields, and trace gas abundances, VESAT utilizes a 450-inclined, 30,000-km altitude circular orbit to achieve consistent, regular coverage of the entire globe with minimal day-to-day variations in spacecraft operations, allowing uplink/downlink operations to be conducted effectively and inexpensively in a university setting. An integrated hardware procurement approach, wherein a single contractor is responsible for the design, manufacture, and integration of the entire space.craft, including the instrument payload, enables significant savings in spacecraft/payload cost and schedule.

INTRODUCTION

The Venus Environmental Satellite (VESAT) is being developed to conduct a systematic, focussed investigation of kcy environmental parameters diagnostic of global circulation, local meteorology, and chemical processes within the dynamically- and chemically-active Venusian atmosphere. During the year-long orbital reconnaissance, these characteristics (e.g., wind- fields; atmospheric and surface temperature fields; cloudtop pressure-ahitudc;cloud particle sizes; and the abundances of chemically-activeand dynamically-diagnostic trace species, including CO, H_2O, OCS, and SO_2) will be mapped globally and daily at 15-120 km spatial resolution and at several levels in the atmosphere from the surface to 90 km altitude. This information will be used to address (1) global circulation, including the roles solar-induced thermal tides, atmospheric eddies, and travelling and gravity waves have in powering the atmosphere's unusual global super-rotation, (2) tropospheric meteorology, including the development and evolution of convective and/or orographically-induced clouds and/or storms in the upper troposphere, and (3) atmospheric and surface chemistry, including sulfuric acid cloud formation/dissipation processes and surface. weathering caused by the interaction of the hot, dense lower atmosphere with volcanically-generated surface material.

VESAT takes advantage of unique characteristics of the Cytherean environment, together with recent advances in detector technology, to accomplish its seemingly-ambitious goals cheaply and efficiently. VESAT utilizes Venus's intense flux of reflected visible and indigenous thermal radiation, together with the 2-D multiplexing, photon-counting capabilities of modern detector arrays, to achieve ~100:1 S/N measurements with small apertures (c 35 mm in diameter), with commensurate savings in overall instrument size, mass, and cost. The number of instruments is kept small by exploiting in particular Venus's spectrally-rich and bright 0.9 -2.5 μm spectrum, over which a near-infrared imaging spectrometer maps chemical abundances at several levels, winds in the middle atmosphere, cloudtop pressure-altitudes, and the spatial variability of surface temperature and emissivity.

SCIENCE OBJECTIVES

VESAT's focussed set of science goals include:

- Principal science goal: Global circulation, including global super-rotalion
- Ancillary science goal: 1 ocalized meteorology, including cloud formation/dissipation and cloud chemistry
- Exploratory science goal: Surface Science, including volcanism

1. Global Circulation : The Super-Rotation Enigma

The primary goal of VESAT is to resolve the key enigmatic problem of Venusian dynamics, that is: What powers and sustains the global super-rotation? On Venus, the 70-km altitude cloudtops revolve around the planet at an angular velocity sixty times greater than the rotational angular velocity of the underlying surface, presumably powered by sunlight which is primarily deposited in this region. Yet, the peak of the atmospheric momentum resides far below, near the 20-km level. How dots this situation arise? Furthermore, how dots the equatorial region sustain its momentum against the drain of angular momentum which necessarily accompanies the poleward transport of relatively-warm equatorial air ? Previous spacecraft observations (e.g., by Galileo: Belton *et al.*, 1991; Carlson *et al*,]991) indicate that in both hemispheres the meridional (north-south) flow is indeed poleward at the cloudtops. Thus onc would expect the equatorial atmosphere to be moving more slowly relative to the planet's rotational direction than the atmosphere at middle and high latitudes, perhaps even moving in the retrograde direction as occurs at low latitudes on Earth. Yet, Venus exhibits a nearly-uniform prograde angular-momentum profile from the equator to high latitudes. Again, how dots this situation arise?

A number of hypotheses for the super-rotation have been proposed involving(1) thermal tides produced near and within the sunlight-absorbing 50-70 km middle and upper cloud regions (Fels and Lindzen, 1974; Baker and Leovy, 1987; Leovy, 1987; Newman, 1992) and/or (2) the vertical transport of momentum from the surface by the mean meridional circulation (Gierasch, 1975). Transport of angular momentum is proposed to occur meridionally and vertically via an array of hypothesized small-scale eddies, large-scale travelling waves, and Vertically-propagating gravity waves. Duc to spatial and temporal coverage and resolution problems, such hypotheses cannot be verified by either existing spacecraft observations or expected Earth-based or descent probe measurements. Earth observations cover only a 2 month period every 18 months for ˜100 km (0.25 are.-scc) studies, constraining measurements to a narrow range of local times and sub-Earth longitudes on this slowly-rotating planet. As for planetary flyby or orbiter spacecraft, no spacecraft except for Galileo has been capable of covering winds on both the day and nightsides, and Galileo itself had just three hours to measure the nightside component, i.e., 0.1% of a Cytherean day (117 Earth day). Furthermore, the measurement of small-scale eddies and waves requires spatial and temporal resolution on the order of tens of kilometers and minutes-to-hours, respectively. This spatial requirement is beyond ground-based capabilities and such dense temporal sampling has thus far not been obtained by spacecraft for more than a fcw days (i.e. Galileo. The spin-scanned Pioneer Spacecraft permitted just four maps a day). Obviously, neither can a reasonable. (less than a fcw hundred craft) armada of short-lived descent probes achieve the required spatial and' temporal coverage and sampling required to resolve eddies from mean winds.

VESAT, by globally mapping the cloud-tracked windfield at high spatial and temporal resolutions over an extended range of altitudes, time, and solar lighting conditions, will delineate the roles solar-induced thermal tides, eddies, travelling waves, and gravity waves have in powering and transporting atmospheric super-rotation throughout the middle and upper atmospheres. VESAT, by additionally mapping the upper cloudtop pressure and the temperatures in and above this cloudtop once per clay, will also quantitatively assess how wc]] Venus adheres to cyclostrophic balance, as well as measure the horizontal momentum and heat transports duc to the mean eddy circulations.

2. Meteorology Cloud Formation, Dissipation, and Chemistry

Venus's atmospheric chemistry involves unique chemical cycles (H_2SO_4 cloud formation from water and sulfur dioxide, carbon monoxide and OCS produced by photochemistry, etc). The concentrations, distributions, and time variations of atmospheric water, sulfates and, CO are currently poorly constrained. A global decrease in atmospheric SO_2 witnessed by Pioneer Venus since 1979 has been attributed to volcanism (Esposito *et al*, 1979). Alternatively, other investigators (Clancy and Muhleman, 1991; Bézard *et al*., 1992) have attributed this variation to dynamical processes. Indeed, recent results from Galileo/NIMS (e.g., Carlson *et* al.; 1993 Collard *et al*, 1993) indicate (1) a global variability in CO, and (2) regional and localized variabilities in the masses of clouds and the sizes of the sulfuric particles within them, indicative of spatially-varying dynamical and chemical processes. To address such chemical/dynamical issues, VESAT, using near-it spectroscopic techniques pioneered by Galileo/NIMS and groundbased observers, will daily map out abundances of chemically-active species and upper and lower cloud opacities, particle sizes, and mass column densities on 15-km scales.

3. Surface Science

Recent observations by Galileo/NIMS (Carlson et al. 1991) and groundbased observers (Lecacheux *et* al. 1991; Meadows ***et al. 1992)*** in the. relatively transparent 0.99 to 1.03, 1,1, and 1.18 μm windows demonstrate a clear correlat ion of thermal flux with the surface topography. Venus 4-D will exploit this result, correlating 1-pm thermal flux with Mage]lan..derived surface topography to obtain constraints on surface emissivity, surface air temperature, and vertical thermal profiles from O to 10 kilometer pressure altitude, Spatial and temporal variations in surface air temperature will yield constraints on dynamics in the lowest regions of the atmosphere. Moreover, volcanic activity should be readily observable via temporal and spatial variations in the surface thermal flux, and by localized variations in H_2O, SO_2, OCS, and other volcanically-generated speci es.

MEASUREMENT OBJECTIVES

Figure 1 shows representative examples of the kind of global imagery VESAT expects to acquire, based on previous Galileo and Venus Pioneer mission experience. Figure 2 shows atmospheric levels where various cloud opacities, winds, pressures, temperatures, and chemical constituents arc to be measured. '1'able I indicates the primary observational wavelength(s), measurement coverage and resolution, and measurement uncertainties expected for each of these parameters,

MISSION DESIGN

1 Mission Concept

VESAT orbits Venus every 21 hours in a circular, 45-degree. inclined, 30,000-km altitude orbit. Three remote sensing instruments utilize this unique geometry to measure dynamically- and chemically-important atmospheric parameters over a wide range of altitudes, covering almost the entire globe each day. Some. surface temperature information (in particular, its daily and spatial variability) is obtained as well; this will be correlated with known topography to deduce constraints on at mospheric temperat ure variations from the mean surface level to approximately ten kilometers altitude (the. height of Maxwell Montes), and to search for and characterize volcanic activity (including emissions and surface flows).

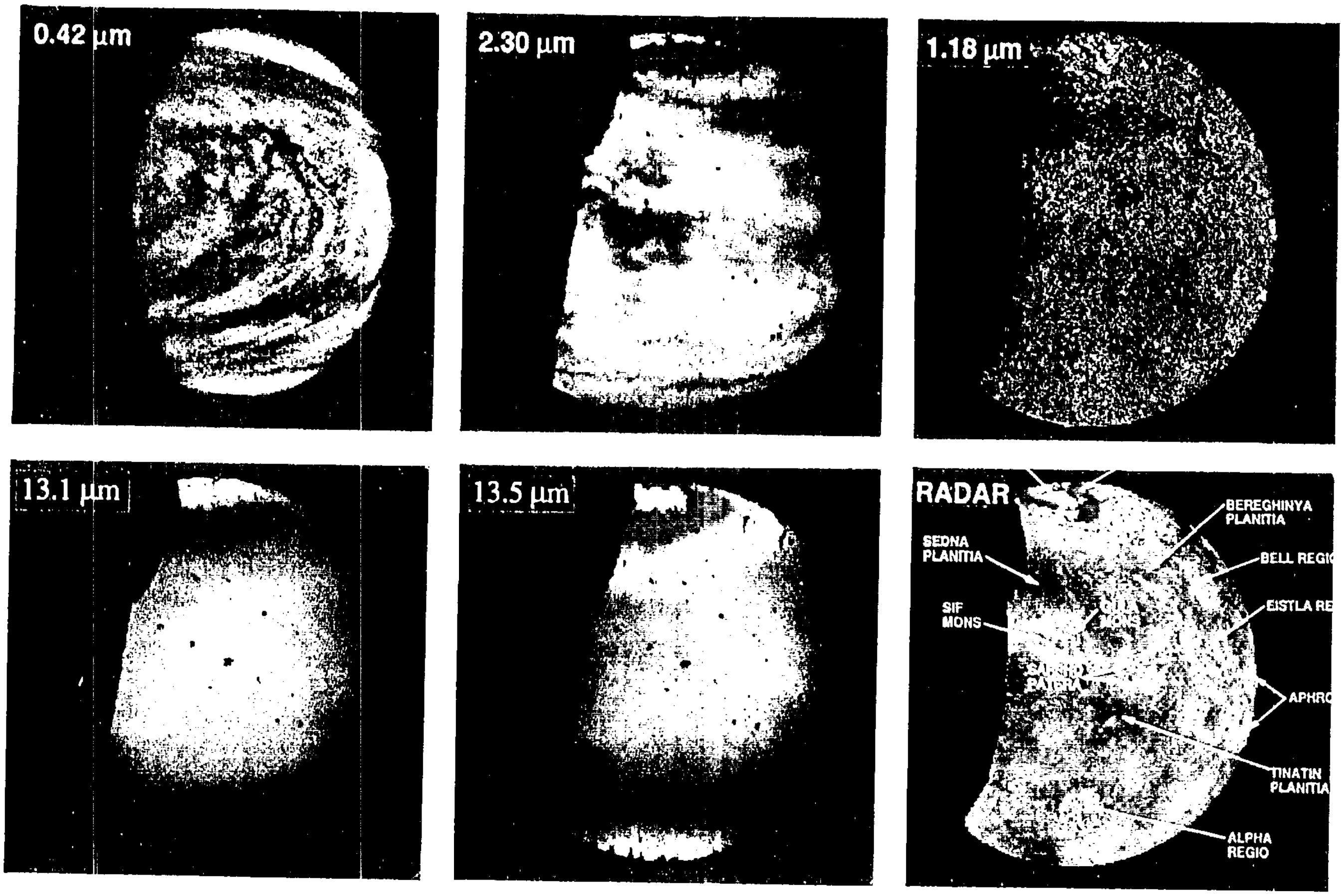


Figure 1 (Above). Representative imagery/maps expected from **VESAT** derived from the temporally- and spectrally-limited Galileo SS1 violet and NIMS near-ir full-disk dayside and nightside imagery/map set, Violet filter (top left) and 2.3 µm images show cloud features near 50 and 70 km altitude, respectively, from which high- and middle-level atmospheric winds can be derived. Surface radiation effects (e.g., the relatively cool peak of Maxwell Montes near the North Pole; c.f. radar image below) are discernible in the 1.18-µm low S/N NIMS map (here uncorrected for limb-darkening and residual cloud effects). Cloudtop and atmospheric thermal emission near 70 and 75 km observed at 4.56 and 4.84 µm by NIMS will be observed at 13.1 and 13.5 µm by VESAT. VESAT's improved spectral coverage, increased S/N, and additional viewing capabilities (dayside near-ir views; nightside views unobscured by S/C booms, here causing the holes in the NIMS data) extends significantly Galileo's capability to measure temperatures, pressures, and abundances.

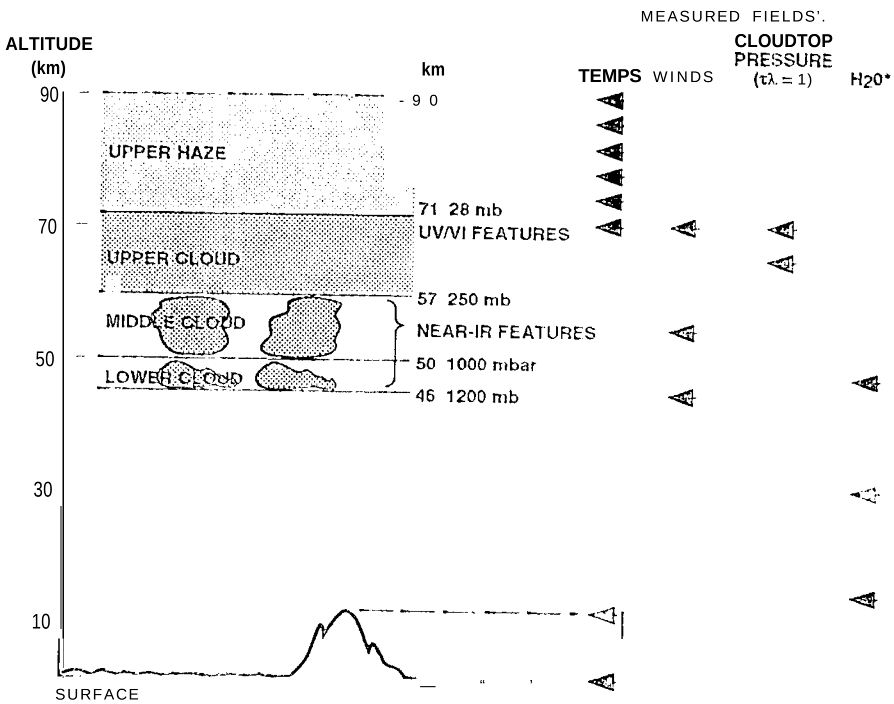


Figure 2 (right). Measurement objectives. VESAT will obtain wind, temperature, pressure, and compositional information at the indicated levels.

* OTHER SPECIES TO BE MEASURED NEAR 40 km ALTITUDE: SO_2, CO, OCS, HDO

** CLOUDTOP PRESSURES FOR UPPER CLOUD ALSO MEASURED

TABLE I

VESAT MEASUREMENT OBJECTIVES AND UNCERTAINTIES

SPATIAL COVERAGE: GLOBAL TEMPORAL COVERAGE: <DAILY FOR1 EARTH YEAR				
MEASUREMENT OBJECTIVE	BEST DIAGNOSTIC WAVELENGTHS (μm)	BEST GLOBAL SPATIAL (km)/ TEMPORAL (hr) SAMPLING	MEASUREMENT PRECISION/ ACCURACY •	
CLOUD DISTRIBUTION AND WINDS AT:			m/sec	m/sec
50-km ALTITUDE (NIGHT)	2.30	15 km/0.5 hr	0.8	0.8
50-km ALTITUDE (DAY)	230	15 km/0.5 hr	0.8	0.8
	0.95	15 km/0.1 hr	0.5	0.5
70-km ALTITUDE	0,36	15 km/0.1 hr	0.5	0.5
CLOUD/ATMOSPHERIC/SURFACE TEMPERATURE AT:			°K	°K
SURFACE (1-10 km)	1.18	50 km/0.5 hr	0.1	2.0
65 km	11.5	25 km/21 hr	0.1	0.5
70 km	13.1	120 km/21 hr	0.1	0.5
75 km	13,5	120 kmRl hr	0.1	0.5
80 km	13.8	120 km/21 hr	0.1	0.5
85 km	14.3	120 km/21hr	0.1	0.5
90km	14.7	130 km/21hr	0.1	0.5
CLOUDTOP (τ_λ - 1) PRESSURE NEAR:			km-"	km
65 km	11.5113.1	120 km/21hr	<0,1	0.2
70 km (day):	2.0	15 km/0.5 hr	0.2	0.2
H20 ABUNDANCE AT:			ppm	ppm
10KM	1.18/1 .05	50 km/0.5 hr	5	15
35 KM	1.74/1.75	30 km/0.5 hr	-3	10
45 KM	2.42/2.30	30 km/0.5 hr	3	10
CHEMICAL ABUNDANCES BELOW CLOUDS (35-45 km)			%	%
CO	233n,30	30 km/0.5 hr	10	30
OCS	2.46/2.30	50 km/0.5 hr	10	30
SO_2	2.4712.30	50 km/0.5 hr	30	60
HDO	2.40/2.30	50 km/0.5 hr	30	50

• PRECISION DENOTES THE UNCERTAINTY IN TEMPORAL OR PIXEL-TO-PIXEL SPATIAL VARIATIONS< AND IS DRIVEN BY THE S/N OF THE MEASUREMENT. ACCURACY DENOTES THE UNCERTAINTY IN ABSOLUTE QUANTITIES, TYPICALLY DRIVEN BY UNCERTAINTIES IN THE ABSOLUTE CALIBRATION OF THE INSTRUMENTS AND THE MODELLING/ANALYSIS PROCEDURES USED TO DERIVE SUCH QUANTITIES. FIGURES BASED ON (1) CARLSON EI AI (1891), BAINES AND CARLSON (1891), AND LIMAYE AND SOUMI (1981) FOR WINDS; (2) CARLSON ET AL (1991) AND CRISP ET AL (1991) FOR ABUNDANCES AND PRESSURES, AND (3) SCHOFIELD AND TAYLOR (1983) AND CARLSON ET AL (1991) FOR TEMPERATURES.

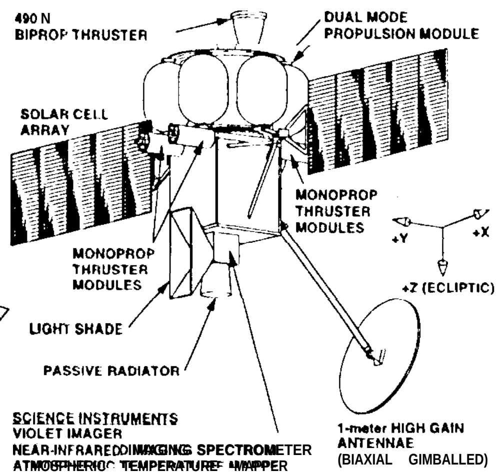
2 Launch Opportunities/Mission Mass Breakdown

Launch opportunities occur approximately every eighteen months. Specific opportunities exist June 2-17, 1999 and December 26, 2000 - January 10, 2001. For these launch windows, a Type 1 trajectory using a Delta 11 7925 launch vehicle places the VESAT spacecraft in orbit with > 130 kg of dry-weight margin. For the June 1999 launch window, the trip time ranges from 125 to 136 days, with Venus orbit insertion occurring about October 15, 1999. launch C_3 is 10.4 -11.4 km^2/s^2, and delta-V for Venus orbit insertion is 2.3 km/sec. launch vehicle throw mass to Venus is 947-963 kg, including 7% reserve mass margin. With 43 kg of hydrazine (1S1' = 220 see) used to perform 100 m/sec of trajectory course maneuvers, and 481 -486 kg of bipropellant mass (ISP = 308 sec) used for Venus orbit insertion, the dry spacecraft mass available to be delivered on-orbit is 422 -438 kg, some. 200 kg greater than the VESAT payload of 227 kg. A detailed S/C and mission mass breakdown is depicted in 'l'able 11.

TABLE 1 I

SPACECRAFT COMPONENT MASS AND POWER ESTIMATES

SUBSYSTEM	MASS (kg)	POWER TO MISSION RATE (W) CRUISE	NORMAL ORBIT OPERATIONS	DATA RECOVERY
STRUCTURE	37.0	0	0	0
MECHANISMS	9.0	0	0	0
TT&C	10.4	6.6	6.6	51.6
POWER	41.8	4.0	4.0	4.0
CC&DH	7.4	9.5	14.0	14.0
ADCS	13.9	24.0	24.0	24.0
THERMAL	5.0	20.0	10.0	5
PROPULSION (DRY)	77.2	10	10	10
PAYLOAD	25	15	35	35
SUBTOTAL (DRY)	226.7	89.5	103.6	143.6
PROPELLANT	529 (MAX)			
MARGIN (3°/0)	23			
REQUIRED DELTA II-INJECTED MASS TOWARD VENUS (1999 LAUNCH)	778.7 (MAX)			
DELTA II CAPABILITY	947 (MIN)			
MARGIN	- 168 (MIN)			



PRELIMINARY DESIGN 1992

1994 CHANGES:
- BODY-FIXED SOLAR CELLS (EXTENDED ARRAY ELIMINATED)
- SCAN MIRRORS ELIMINATED
- LIGHT SHADE REDESIGNED TO ENCOMPASS ENTIRE INSTRUMENT PACKAGE

3. Mission Requirements

Preliminary mission requirements include:

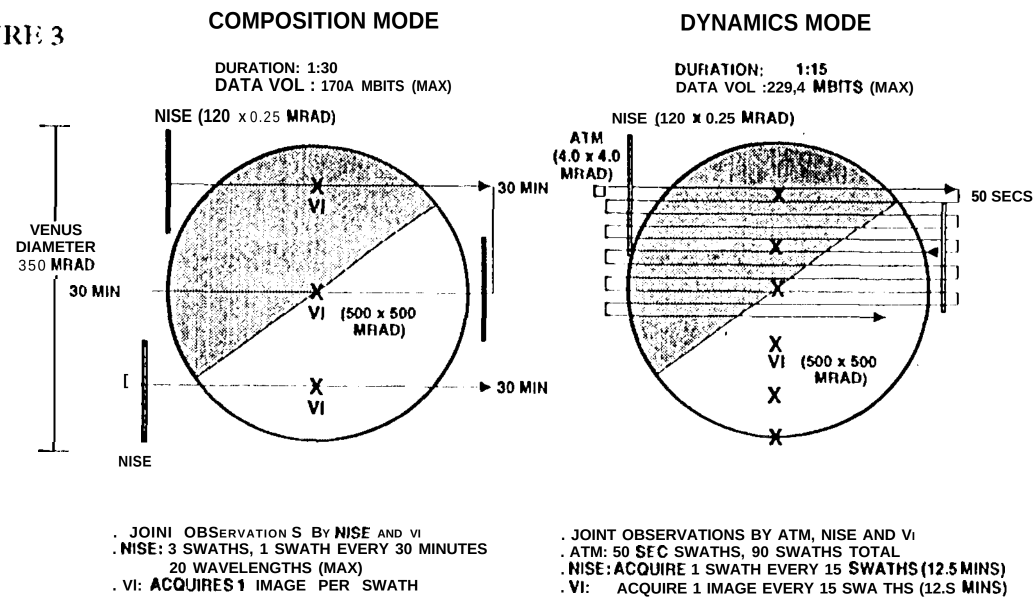
- Launch vehicle: Delta II 7925.
- IO: $C_3 \le 12$ km^2/s^2; $V_\infty < 3.1$ km/s
- Mission/spacecraft lifetime ≥ 1.5 years, including 1 year in Venus orbit
- Carry at least 100 m/s of delta-V for trajectory correction maneuver
- Perform one major propulsive S/C maneuver: Venus orbit insertion
- Venus orbit: 30,000 ± 3000 km altitude at 45” ± 10° inclination

4. Observational Time Line and Data Volume

A salient feature of the VESAT mission is the regularity of science measurements. Each day, the 21-hour complete-orbit observation period is comprised of seven identical three-hour segments. During each segment, the full disk of Venus is scanned, via S/C slews, in two different modes (c. f., Figure 3). For the first 90 minutes, the "Composition Mode" is used, wherein atmospheric. composition information is obtained via push-broom 0.25 -mr/sec scanning of the. planet with the Near-infrared imaging Spectrometer Experiment (NISE). In addition, during each of the three scans which together cover the disk, one 10-msec exposure violet image is snapped "on-the-fly" in the, middle of the scan with the Violet Imager (VI) for measuring the 70-km-altitude windfields. Subsequently, the next 75 minutes are used to complete gathering of dynamics measurements. This "Dynamics Mode" acquires multi-level measurements of atmospheric temperatures utilizing the mid-infrared Atmospheric Temperature Mapper (ATM) and 0.95-pm and 2.3-μm determinations of the SO- and 56-km windfields using NISE, again in push-broom scanning mode. Additional 70-km wind information is obtained with VI, at 12.5-minute resolution vs the 30-minute resolution obtained in the Composition Mode. The 15-minute remainder of the three-hour observing cycle is used for calibrations, repositioning, and for contingency,

The maximum data volume acquired is 2.8 gigabits per day under this scenario. Using (1) editing to discard unwanted views of space, over-saturated dayside NISE pixels and under-threshold nighttime VI pixels, and (2) standard 2:1 compression techniques such as being developed for Galileo/NIMS, Galileo/SSI, and Cassini/VIMS, the maximum downlink data volume may be readily reduced to less 1 gigabit per day. This is readily accommodated by the daily VESAT 3-hour downlink with a DSN 34-meter ground station.

FIGURE 3



FLIGHT SYSTEM DESIGN

1 Requirements

in addition to meeting the mission requirements discussed above, the S/C must satisfy the following requirements to achieve mission success:

- Provide attitude control to 1 mrad and knowledge to 0.5 mrad
- Provide thermal control during cruise and Venus orbit operations
- Provide 100 kbps telemetry for 3 hrs/day downlink to the 34-m DSN at 0.3 AU
- Provide storage for 1 gigabyte of science and engineering data.

2 System Design

The VESAT spacecraft is a 3-axis stabilized design (Table 11), designed and built by Ball Aerospace based on their similar three-axis stabilized Geosat Follow-On S/C design. It uses subsystems based on proven components to provide attitude control, propulsion, thermal control, power, command control and data handling (CC&DH), and communications functions during the mission and to allow the S/C to act as a dual-axis gimbal to point the science instruments. These subsystems and the instrument payload are supported by a simple and compact structure fabricated from aluminum honeycomb. The resulting configuration is small and light enough to be injected into the mission orbit by a Delta-7925, with >160 kg of payload margin, A separate bi-prop/mono-prop propulsion module is used for trajectory correction burns and Venus orbit insertion. Power is supplied via body-mounted solar cell arrays.

INSTRUMENTS

The VESAT instrument complement consists of three compact remote-sensing imager/ mappers which are radiatively cooled and are recessed behind a common lightshade which forms one end of the cylindrically-shaped spacecraft. This instrumentation includes a Violet Imager (Vi), Near-infrared imaging Spectrometer Experiment (NISE), and Atmospheric Temperature Mapper (ATM), depicted in Figure 4. These instruments are co-aligned, viewing Venus through an observing porthole located on the lightshade. Radiative coolers are oriented along the spacecraft z-axis, cooling the instrument focal planes to less than 95 K. Scanning is accomplished without the use of mirrors, utilizing just S/C slews.

Table 111 depicts salient characteristics of the three instruments. The instrument package weighs less than 14 kg and consumes less than 14 watts.

Views of space and of a well-calibrated and temperature-monitored aperture door are used to calibrate. the 11-15 μm ATM instrument. VI and NISE pixel-to-pixel relative ("flat field") calibrations are accomplished via diffusers located on their aperture doors which, when shut, are placed in the line of sight of the Venus dayside. Absolute calibrations are. unnecessary for VI, since this instrument is used only for feature tracking. Observations of the well-established and constant Venus dayside continuum reflectivity between CO absorption bands, also observed through the diffuse.r, provide both pixel-to-pixel relative calibration along the slit and relative spectral calibration. Absolute calibrations are obtained via star calibration and/or comparisons with ground-based near-ir observations of Venus acquired during the mission.

TABLE III

VESAT INSTRUMENT CHARACTERISTICS

	VIOLET IMAGER	NISE	ATM
FOCAL LENGTH	42 mm	142 mm	37.5 mm
F/#	8	4.6	1.5
DIAMETER	5.24 mm	31 mm	25 mm
SIZE	13x12 x12cm	30x15 x 15 cm	25x15 x 10 cm
SPECTRAL RANGE	360 nm	1.0- 2.5 MICRON	11.5 -14.3 MICRON (6 BANDS)
SPECTRAL RES.	40 nm	2.5 nm	0.6 MICRON, 0.2 MICRON
FOOTPRINT	17 km	8 km	138 km, 27 km
IFOV	0.5 mr	0.27 mr	4.2 mr, 0.84 mr
FOV	29.34 deg	7.6 deg	N/A
MASS	2.5 kg	4.5 kg	4.8 kg
POWER	5 WATTS	6 WATTS	2.5 WATTS
DATA	14 MBITS/IMAGE	SELECTABLE	1385 BPS
EXPOSURE TIME	10ms	2 SEC.	0.4 & 0.08 SEC
SNR	100	21	500
DETECTORS	1k x 1k 21 MICRON	640 X 480 SWIR 19 MICRON	HgCdTe (150 MICRONS) -5 HgCdTe (5 x 30 MICRON)
QUANTIZATION	14 BITS	12 BITS	14 BITS

PROGRAM MANAGEMENT/MISSION OPERATIONS

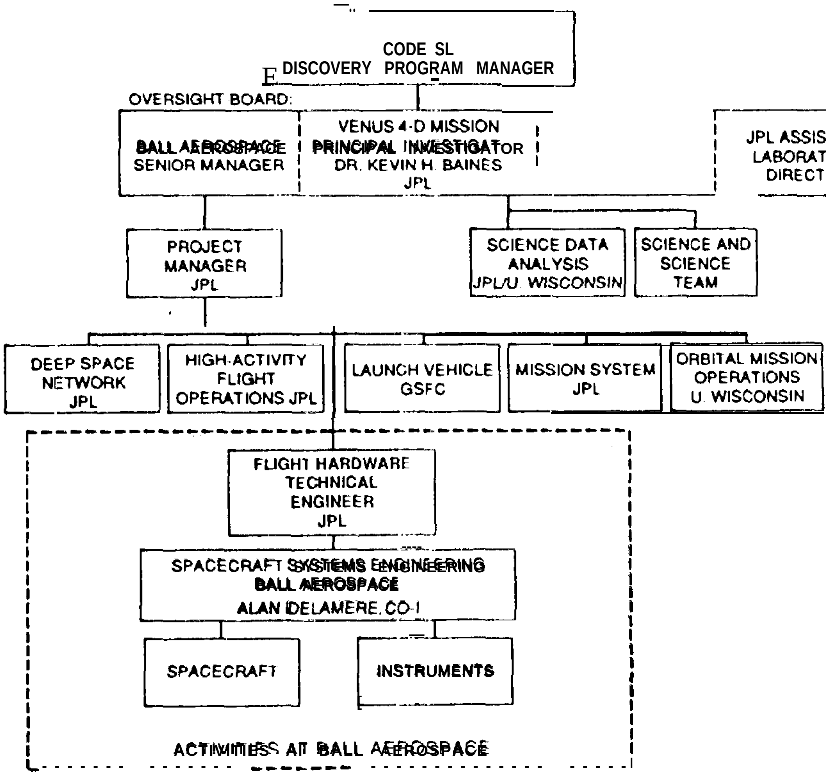
Effective management is the key to enabling this and other Discovery missions. The tight cost and schedule constraints (less than $150 million hardware development/delivery/flight costs through launch + 30 days, to be achieved over less than three years) necessarily means a streamlined management approach which can find effective solutions quickly.

Overall, VESAT utilizes a management **structure similar to those previously successfully** employed for the Solar Mesospheric Explorer and the Ball/Aerospace RM 1 programs. A small set of manufacturers and institutions arc integrated together, utilizing their most cost-effective expertise to manage particular facets of the mission (cf., Figure 4). In particular, onc hardware manufacturer, in this case, Ball Aerospace, has primary responsibility over all hardware design, fabrication, integration, test, and delivery, including all the science instruments. J])]., led by the Principal investigator and Project Manager, has overall mission responsibility. A J]'], Flight Hardware Technical Engineer oversees the spacecraft and instrument hardware development, integration, and test activities on"-site at Ball Aerospace.

At JPL, mission design, navigation, and the end-to-end information system tasks arc accomplished. High activity flight operations arc also planned and conducted there. On-orbit routine mission operations arc managed by the SSEC at the University of Wisconsin.

On the science team, each Co-Investigator is responsible for aiding the PI in overseeing a specific facet of the Mission. In particular, each science instrument has an expert Co-I, previously experienced in developing and flying a comparable flight instrument, assigned to it to ensure that science requirements are met, Dr. Robert W, Carlson, 1'1 of the Galileo Near-lnfrarcd Mapping Spectrometer (NIMS), is the instrument CO-1 for the VESAT Near-infrared Imaging Spectrometer Experiment. Dr. Frederic Taylor, PI of the Pioneer Venus Orbiter Infrared Radiometer (OIR), is the instrument Co-I for the VESAT Atmospheric Temperature Mapper.

FIGURE 4



CONCLUSION: VESAT IMPACT ON SCIENCE, SOCIETY, AND PLANETARY EXPLORATION

VESAT addresses fundamental issues pertaining to atmospheric dynamics, atmospheric composition, cloud/atmospheric chemistry, and surface properties in a uniquely alien environment which represents one extreme of the kinds of atmospheres found in the Solar System (i.e, hot, dense CO_2 atmosphere vs cold, thin CO_2 Martian case or cold reducing atmospheres of the outer Solar System). Venus is the only planet (save, perhaps, the Earth) where crucial atmospheric variables such as winds, temperatures, pressures, and abundances of chemically-active species can be observed in the four spatial and temporal dimensions. At the same time, the limited effects of seasonal and surface variability on atmospheric circulation (2.6° obliquity; lack of oceans for heat transport and associated meteorology) compared to that found on the Earth) render Venus a particularly simple global laboratory for understanding Earth's own dynamic meteorology and atmospheric chemistry. Building on Venus Pioneer and Galileo observations, VESAT will in particular scrutinize the parameters important for understanding Venus's 4-day super-rotation, thereby ***resolving one*** of the most **important and intriguing problems presently facing planetary** dynamacists.

VESAT merges the most capable and cost-effective aspects of the industrial, university, and NASA communities to quickly and efficiently produce and fly a planetary orbital mission resulting in a prodigious quantity of high-quality science at low cost. Direct undergraduate and graduate student involvement in planetary spacecraft operations and science analysis will contribute substantially to the Nation's space flight and science infrastructure. In the end, it is expected that the Venus 4-D mission will serve as the example of how low-cost, high-yield planetary missions should bc conducted in the 21st century.

Yet, VESAT will produce more than ncw spacecraft, science, and scientists. Given the unique capabilities this mission has in revealing the dynamical middle-atmosphe~c otherwise hidden beneath the planet's perpetual upper cloud cover, this mission will likely stimulate unusual public interest. In particular, three-dimensiona] movies of Cytherean meteorology (storm system development and dissipation) and global circulation will be of interest, as will any imagery of lightning or movies of active surface volcanism.

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